전단벽식 아파트에서 시공중 슬래브 및 동바리의 응력변화에 대한 연구

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Study on Stress Variation in Slab and Support of Shearwall-Type RC Apartment during Construction

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Abstract : Safety and efficiency in the construction of RC structures mainly depends on optimal operation of shore-slab systems. The disasters in RC construction are mainly due to excessive load applied to falsework and premature removal of supports. Development of sufficient compressive strength of early-age concrete is essential for the safety of structures during construction. Most of studies on shore-slab interaction have focused on flat slab structures. In this study, load distributions in floor slabs and supports during the construction of shear wall-type RC apartment building structures is investigated using finite element analysis.

초 록 : 철근콘크리트조 공사의 안전성과 효율성은 동바리-슬래브거푸집의 최적의 운영에 달려있다. 철근콘크리트공사에서의 사고는 주로 가설공사에 과도한 하중이 작용하였거나 동바리를 조기에 철거하기 때문에 발생한다. 콘크리트의 조기압축강도발현이 공사중구조체의 안전에 중요하다. 슬래브-동바리의 상호작용에 관한 연구는 주로 무량슬래브 구조에 대하여 이루어 졌다. 본 연구에서는 전단벽식 철근콘크리트조 아파트에서 슬래브와 동바리에서의 하중분포를 유한요소법을 이용하여 조사하였다.
Key Words : shoring, construction cycle, shore-slab interaction, construction safety

1. Introduction

In concrete construction, formwork is a key factor affecting construction safety, time, and cost. Hence, construction efficiency can be improved by optimally operating shore-slab system. Premature removal of support or excessive loading to formwork leads to construction failure. Sufficient strength development of early-concrete is essential for early striking of form.

Grundy and Kabaila[1] did a pioneering work on the study of shore-slab interaction in multistory reinforced concrete structures. They proposed a simplified method for the estimation of load flow in slabs and shores with assuming that shores are rigid and the stiffness of slab is time-independent, which was proved to be unrealistic by many investigators. Taking more realistic assumptions in analysis model, Liu et al[2] concluded that the simplified method is appropriate in predicting maximum slab moment and shore loads, but it is necessary to introduce modification coefficient to assess accurate load distribution. Stivaros and Halvorsen[3] found that the most significant factor in distributing construction loads to slabs and supports is the shoring-system stiffness. Design consideration for formwork and development of realistic approach for the determination of construction load distribution are compre-

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hensively covered by Chen and Mosallam[4]. Recently, floor load distribution in shear wall with flat plate structure is studied by Fang et al[5].

The shoring operation in Korea is similar to back-shoring rather than reshoing, called clearing(Moragues et al[6]), in which initially installed shores are partially removed after few days of concrete curing and remained shores are intact until they are removed.

In this study, five apartment building units are selected for the investigation of force transmission through shores during construction of shearwall-type reinforced concrete building structures. Analysis is carried out for the largest size of slabs surrounded with shearwall in each units, in which boundary conditions are idealized according to the support condition of slab edge. Considering the aging effect of concrete, load transmitted through shores as construction operation continues is examined and compressive, shear stresses in floor slab are examined using finite element analysis. Based on data available through this study, estimation of load transmission in shores is investigated.

2. Assumptions in Modeling

Many factors influence on the load distribution in slab and shore. To minimize the complicated nature of slab-shore system while maintaining the realistic situation of construction practice assumptions introduced in this study is as follows:

1) Slabs behave elastically, and their stiffnesses are time-dependent.

2) Shores and reshores act as continuous uniform elastic supports and behave elastically.

3) The foundation is rigid and unyielding.

4) The joints between the slabs and walls are rigid-ended and the wall is rigid.

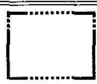
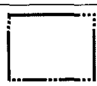
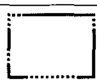
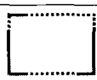
5) Joints between slabs and shores are pin-ended.

Several factors such as concrete placement path, slab support condition, shoring system, construction rate, and the mechanical properties of early concrete are related to the construction load distribution. Construction loads can be classified into dead load due to concrete slab and formwork system and live load due to workers, equipment, and impact. In addition to these loads, horizontal load due to concrete placement should be considered in the design of formwork system. However, in this study, as the lateral stability of slab formwork is constrained by the shear wall formwork, the effect of horizontal load is not included. The impact load is considered only during concrete pouring while the construction live load is considered during concrete pouring and curing. The rate of the concrete strength development depends mainly on the concrete age, cement type, and curing temperature. In this study, a prediction model by Kim et al[7] for estimating modulus of elasticity of early-age concrete is used.

3. Description of Structural Unit

In the modeling of shore-slab system, as living room area is the largest slab surrounded by shearwalls, only this area is modeled to investigate load distribution in slab and shores. The configuration of analyzed slab units is summarized in Table 1, where the boundary condition at slab edge is idealized as shown. The shoring distance and concrete design strength of slab units are 120cm and 240kgf/cm^2, respectively except unit SU-5 whose values are 90cm and 210kgf/cm^2.

Table 1. Summary of Slab Unit

Unit	BC[a]	Size[b](m)	Thickness(cm)
SU-1		5.3×5.1	13.5
SU-2		7.1×7.4	20
SU-3		5.6×5.7	15
SU-4		5.6×6.2	15
SU-5		7.4×6.3	18

Note) a: boundary condition, —— fixed, ······ continuous, b: abscissa ×ordinate

One-story shoring and three-story clearing is normally employed in construction site and the rate of construction is 10 day per story. Steel pipe is used for shoring. A typical concrete casting cycle is

1) stage 1: install a story of shores and forms and cast the floor slab above

2) stage 2: partially remove shores from the lowest shored story

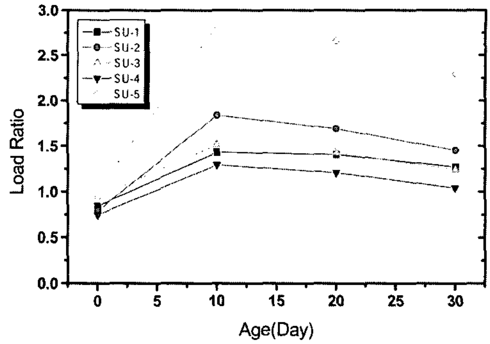
3) stage 3: remove shores from the lowest cleared story

The 4-node plate element and truss element of MIDAS[8] were utilized to model slab and shores, respectively.

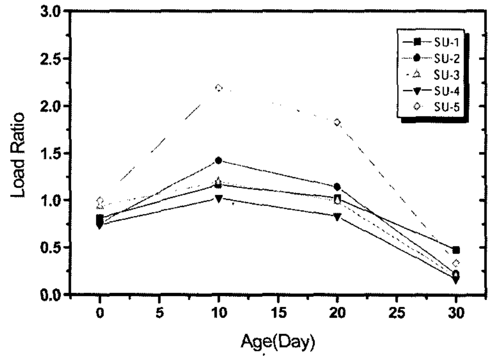
4. Load in Shore and Slab

The ratios of the maximum axial force in shores to the initial one for SU-5 is shown in Fig. 2. The initial axial force is based on the tributory area of each shore. Including impact, dead and live loads for concrete placement, the load on the shore supporting newly cast slab is 838kg/m^2. Then, the initial load on the 0.9m×0.9m-spaced shoring is 680kgf and this is obvious from the Fig. 2. As concrete hardens, the load on shore is reduced. At the next day of concrete pouring 70% of shores is removed and the force in shoring varies very little until the concrete casting of the upper story slab, causing 1920kg of axial force in the reshores. The Euler buckling load for the steel pipe is 1800kg. This is less than the maximum value, meaning buckling of reshores. However, failure didn't occur in the reshores. Presence of friction at the both ends of reshores and live load less than the specified might avoid the buckling.

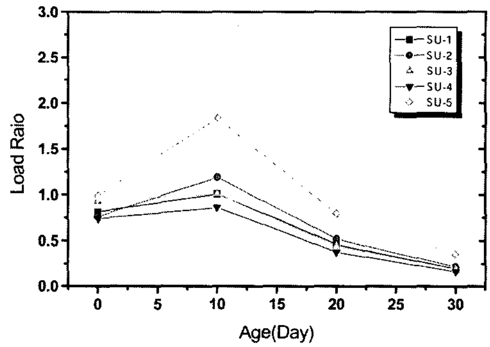
In Table 2, the ratios of the maximum value in each story to the initial load for each shore are listed. The shores in the 1st story shores which is assumed to be supported by unyielding foundation takes 29~182% and compared to the 2nd story 25% more load is transmitted to the 1st story. It is common to use the same size of steel pipe for the entire story. However, if these ratios in Table 2 are considered, it may be possible to use different size of steel pipe for each story, saving construction cost.



(a) 1st Floor



(b) 2nd Floor



(c) 3rd Floor

Fig. 2. Variation of load ratio(SU-5)

Table 2. Maximum load ratio

Unit	Floor		
	1	2	3
SU-1	1.43	1.17	1.01
SU-2	1.84	1.42	1.19
SU-3	1.51	1.20	1.01
SU-4	1.29	1.02	0.86
SU-5	2.82	2.20	1.84

The compressive stress in the slab of SU-5 is shown in Fig. 3. The maximum compressive stress in

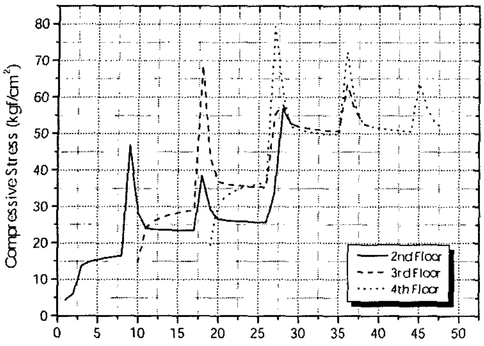


Fig. 3. Compressive stress in SU-5

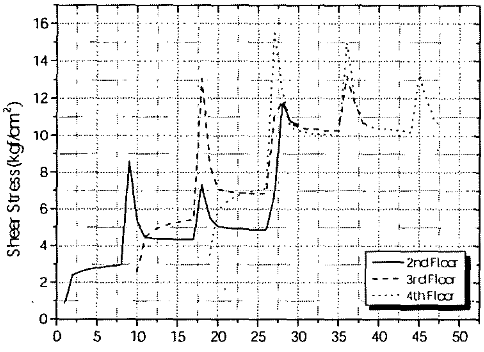


Fig. 4. Shear stress in SU-5

the 2nd floor occurred when reshoring was removed while in other floors, concrete pouring of floor slab above caused the maximum. This trend could be found in the shear stress distribution(Fig. 4).

5. Estimation of Force in Shore

To estimate the range of forces transmitted to shores various size of rectangular slabs with simplified

Table 3. Dimension of simplified slab

Slab size (m)	Slab thickness (cm)	Slab boundary condition	Shore spacing (cm)
5×5	12, 13.5, 15		90, 100, 120
5×6			
6×6	15, 18, 20		
6×7			
7×7			

Note: —— fixed, ······ continuous

Table 4. Force ratio in shores

Slab size	Thickness	Story 1	Story 2	Story 3
5×5	13.5	1.58	1.25	1.06
5×6		1.60	1.30	1.10
5×6	15	1.51	1.17	0.98
6×6		1.82	1.50	1.28

Table 5. Estimated force ratio in shores

Slab	Estimated ratio 1	Estimated ratio 2	Estimated ratio 3	Error(%) 1	Error(%) 2	Error(%) 3
SU-1	1.59	1.27	1.08	9.9	8.1	6.4
SU-2	2.18	1.73	1.45	15.8	17.8	17.9
SU-3	1.61	1.28	1.08	6.1	6.5	6.4
SU-4	1.75	1.42	1.21	26.0	28.0	28.7
SU-5	2.95	2.36	2.06	4.2	6.8	10.8

Note: Error(%)=(Estimated ratio - Ratio in Table 2)/ Estimated ratio*100

boundary condition are analyzed. The dimension of simplified slab units is listed in Table 3. Some of the analysis result is illustrated in Table 4 where shore spacing is 120cm. These ratios are utilized in estimating forces transmitted to shores.

In table 5, the estimated ratios for SU-1, 2, 3, 4, 5 are shown, interpolating the ratios in Table 4. The difference in real and simplified boundary conditions tells the large error in SU-2 and -5. For the rest of slab units the error is less than 10%, indicating the possibility to guess load transmitted to shores.

6. Conclusions

Considering the aging effect of concrete, load variation in the floor slab and shoring system of shearwall-type RC structure is investigated. To find out the possibility to estimate the amount of load transmitted to reshores simplified slab units are analyzed. Based on the analysis result, the following is observed.

1) The reshores supported by unyielding foundation are loaded most severely at the concrete pouring of upper slab and their axial forces exceeded the initial slab dead load by from 30% to 180%.

2) Compressive and shear stresses in the 4th floor slab were the maximum and safety margin for

compressive stress was higher than that for shear stress. Therefore, high shear stress around shores can be a cause for collapse of concrete structure during construction. This overstress may be due to simplified structural modeling of formwork system in which contact area of steel pipe and joist are not included.

3) Deflection of floor slab was the maximum at the 4th floor slab and this is within the allowable limit, but the cracking of slab concrete due to early removal of formwork should be examined.

4) Utilizing the analysis results of simplified slab units, it is possible to guess the load ratio for reshores supported by unyielding foundation. This may be instrumental in arranging shores without sacrificing construction safety.

Acknowledgement

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